Coastal and Near Surface Mixing

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LONG-TERM GOAL

My long-term goals are to increase our understand of the role of turbulence and mixing on the circulation of the ocean and the transport of heat, salt, and other important scalars.

OBJECTIVES

I wish to establish whether the horizontal distribution of heat flux and dissipation rate are related to the distribution of Langmuir cells, as indicated by the density of bubble clouds, and to what extent, if any, the flux of heat and the intensity of mixing are enhanced by Langmuir circulation. Langmuir cells are wind and wave induced flows in the surface mixing layer and consist of counter rotating horizontal vortices with a typical spacing of 10 to 100 m and a length of several hundred meters. They essential form a quasi-coherent structure that has large ($O(0.1 \text{ m s}^{-1})$) vertical velocity at the convergence zone between vortex pairs and, therefore, may enhance the rate of vertical exchange with the atmosphere.

I also wish to establish how turbulent processes, such as friction and vertical mixing, control tidal flows in coastal channels and how these processes can be parameterized in terms of easily measured quantities such as the current, its vertical shear and the stratification of density.

APPROACH

We are using a unique towed vehicle that carries both conventional turbulence sensors and acoustic transducers. Turbulent vertical velocity fluctuations and the rate of dissipation of kinetic energy are measured with shear probes, while temperature fluctuations as small as 10^{-5} °C are measured with an FP-07 thermistor. The vertical flux of heat is estimated from the covariance of the turbulent vertical velocity and temperature. The rate of dissipation is estimated from the variance of the horizontal gradient of vertical velocity. Sonars (two athwartship direct side-scans, one forward directed side-scan and a vertical echo sounder) mounted on the towed vehicle are used to map out the distribution of turbulence with respect to bubble clouds (hence, Langmuir cells) in the near surface zone. A paravane deflects the tow line by about 40 m away from the side of the ship and out of its wake. Measurements were taken in the Marine Boundary Layer Experiment in Monterey Bay.

We have also mounted a broad band acoustic doppler current profiler (ADCP) to the bottom of Cordova Channel in close proximity to our tethered autonomous microstructure instrument (TAMI). The ADCP has provided vertical profiles of current, its shear, stress, turbulent kinetic energy (TKE) and its rate of production, mixing length and eddy viscosity. TAMI has provided the rate of dissipation of kinetic energy and temperature fluctuations and buoyancy frequency at mid depth.

WORK COMPLETED

The field work and data processing are completed. Ten manuscripts have been published or are in press, while four additional manuscripts are in progress.

RESULTS

At a depth of 12 m in the surface mixing layer, the heat flux (the co-spectrum of vertical velocity and temperature fluctuations) peaks at a wavelength of 14 m and there is little contribution to the flux from scales that are longer than 30 m and shorter than 3 m (Fig. 1). When the wavenumber is non-dimensionalized by the Ozmidov scale (the largest vertical motion permitted by stratification) and the heat flux is non-dimensionalized by the rate of dissipation of TKE, then the existing spectra show a remarkable degree of universality (Fig. 1). The peak contribution to the flux is provided by eddies with horizontal lengths that are twice the Ozmidov scale. The efficiency of mixing, the flux Richardson number, is 0.3 which is close to the maximum predicted by most theories. The near surface waters were restratifying in response to horizontal density gradients. The stratification and vertical shear maintained a near critical state (Richardson numbers less than 1/4) throughout the 12 hours of observations (Fig. 2).

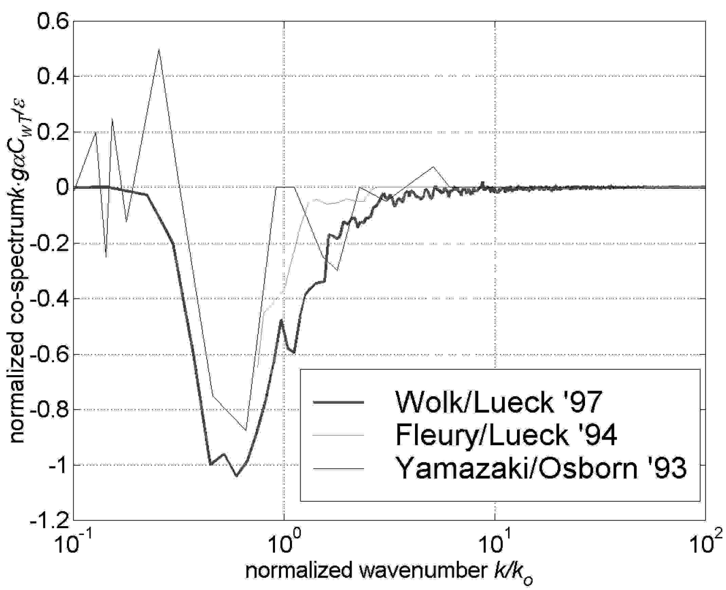

Figure 1. Co-spectrum of vertical velocity and temperature fluctuations (heat flux) normalized by the rate of dissipation of TKE (vertical axis) against wavenumber normalized by the Ozmidov scale (horizontal axis). Fleury /Lueck '94 could not resolve scales longer than the Ozmidov scale, while Yamazaki/Osborn '93 had only a limited data set and, hence, large statistical uncertainty.

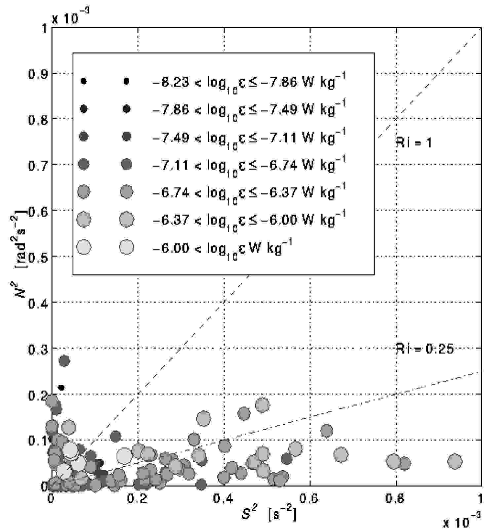

Figure 2. Binned rates of dissipation of TKE in buoyancy frequency (N) and shear (S) space. Lines of constant Richardson number are drawn for reference. For over 12 hours and 20 km of towing the Richardson number remained near it critical value.

In Cordova Channel, the rate of production of TKE closely follows the prediction of the Mellor-Yamada closure model (Fig. 3) while the constant of proportionality (26) is slightly larger than predicted (18).

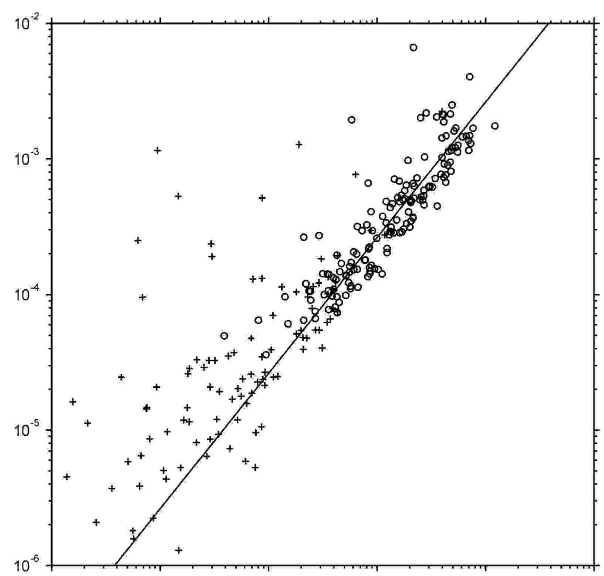

Figure 3. The rate of dissipation of TKE predicted by the closure model of Mellor and Yamada, q^3/l_m, (vertical axis) versus the rate of production of TKE (horizontal axis) deduced from measurements with an ADCP in a tidal channel

IMPACT/APPLICATION

The direct and unambiguous measurement of the vertical flux of heat and other scalars is now fairly routine for atmospheric boundary layer studies but this technique has been used with only limited success in the ocean (except for sensors attached to the bottom or the underside of ice). The successful application of motion correction to the measurement of vertical velocity from a towed vehicle now make it possible to use this direct technique on a variety of platforms such autonomous vehicles, submarines, and moorings. Our measurements of mixing efficiency are consistent with previous attempts in the ocean and, for the very large buoyancy Reynolds numbers that are typically found in the ocean, the observed efficiency is several orders of magnitude larger than predicted from the scaling of laboratory flux laws. The scaling of turbulence needs re-examination.

ADCPs can give robust estimates of turbulence parameters. This tool deserved more routine use for testing models of turbulence at geophysical scales so that we may derive reliable parameterizations of turbulence processes in the coastal environment.

TRANSITIONS

The electronic systems developed for the towed vehicle are now being utilized in Autonomous Underwater Vehicles (AUV) by E. Levine at the Naval Undersea Warfare Centre and our general instrumentation technique has been adapted to AUV measurements by M. Dhanak at Florida Atlantic University. Our signal enhancement technology is being exploited by D. Farmer at the Institute for Ocean Sciences for near surface temperature measurements and is being incorporated into a commercial tide gauge manufactured by ASL Environmental Sciences.

RELATED PROJECTS

1. Hide Yamazaki of the Tokyo University of Fisheries and I are investigating shear instability and internal-wave breaking events near the bottom of the mixing layer in the MBL Experiment using a thermistor chain attached to our towed vehicle.

2. Ed Levine of the Naval Undersea Warfare Center and I are using the small autonomous vehicles *REMUS* to study mixing processes very near the surface. Successful field work was conducted in the New Jersey Bight and Massachusetts Bay.

3. We are working closely with D. Farmer at the Institute of Ocean Sciences to continue using acoustic transducers on our towed vehicle to study the role of Langmuir cells in near surface mixing and wee are comparing acoustic techniques for turbulence measurements against shear probes.

PUBLICATIONS

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